5441 Copy 1

NUWC-NPT Reprint Report 10,860
20 October 1997

Large-Signal Characterization of PMN-PT-Ba (90/10/3)

Robert S. Janus
Mark B. Moffett
James M. Powers
Submarine Sonar Department

Naval Undersea Warfare Center Division
Newport, Rhode Island

Approved for public release; distribution is unlimited. Reprint of a poster presentation made at the *1997 ONR PMN Measurement Workshop*, 9 October 1997, Alfred, NY.

Report Documentation Page

Form Approved OMB No. 0704-0188

1. REPORT DATE **20 OCT 1997**	2. REPORT TYPE	3. DATES COVERED **20-10-1997 to 20-10-1997**
4. TITLE AND SUBTITLE **Large-Signal Characterization of PMN-PT-Ba (90/10/3)**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Robert Janus; Mark Moffett; James Powers**		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Undersea Warfare Center Division,1176 Howell Street,Newport,RI,02841-1708**		8. PERFORMING ORGANIZATION REPORT NUMBER **RR 10,860**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **Office of Naval Research**		10. SPONSOR/MONITOR'S ACRONYM(S) **ONR** 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

NUWC2015 Reprint of a poster presentation made at the 1997 ONR PMN Measurement Workshop, 9 October 1997, Alfred, NY.

14. ABSTRACT

Large-signal measurements are reported for the relaxor ferroelectric, lead magnesium niobate-lead titanate (PMN-PT-Ba, 90/10/3), manufactured by Lockheed-Martin. The material has been formulated to produce optimal performance at 5 degrees Centigrade for application in sonar transducers. Charge and strain measurements were taken at 5?? and 23?? C on a material sample (2x2x10mm) mechanically loaded with 2, 4, 6, 8, and 10 ksi of compressive stress. The sample was electrically dc biased and driven with 5 cycle, 10 Hz pulses to a peak electric field of 2 MV/m. Values for the piezoelectric coefficient, d33, electrical permittivity, E33T, and elastic compliance, S33E, were computed from the measurement data. These three parameters determine the coupling factor, k33, which indicates the effectiveness of the material to convert electrical energy to mechanical energy. For the mechanical loads considered, k33 varied from 0.49 to O.51 at 5?? C, and from 0.44 to 0.49 at 23?? C.

15. SUBJECT TERMS

PMN-PT-Ba, 90/10/3; sonar transducers

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**13**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

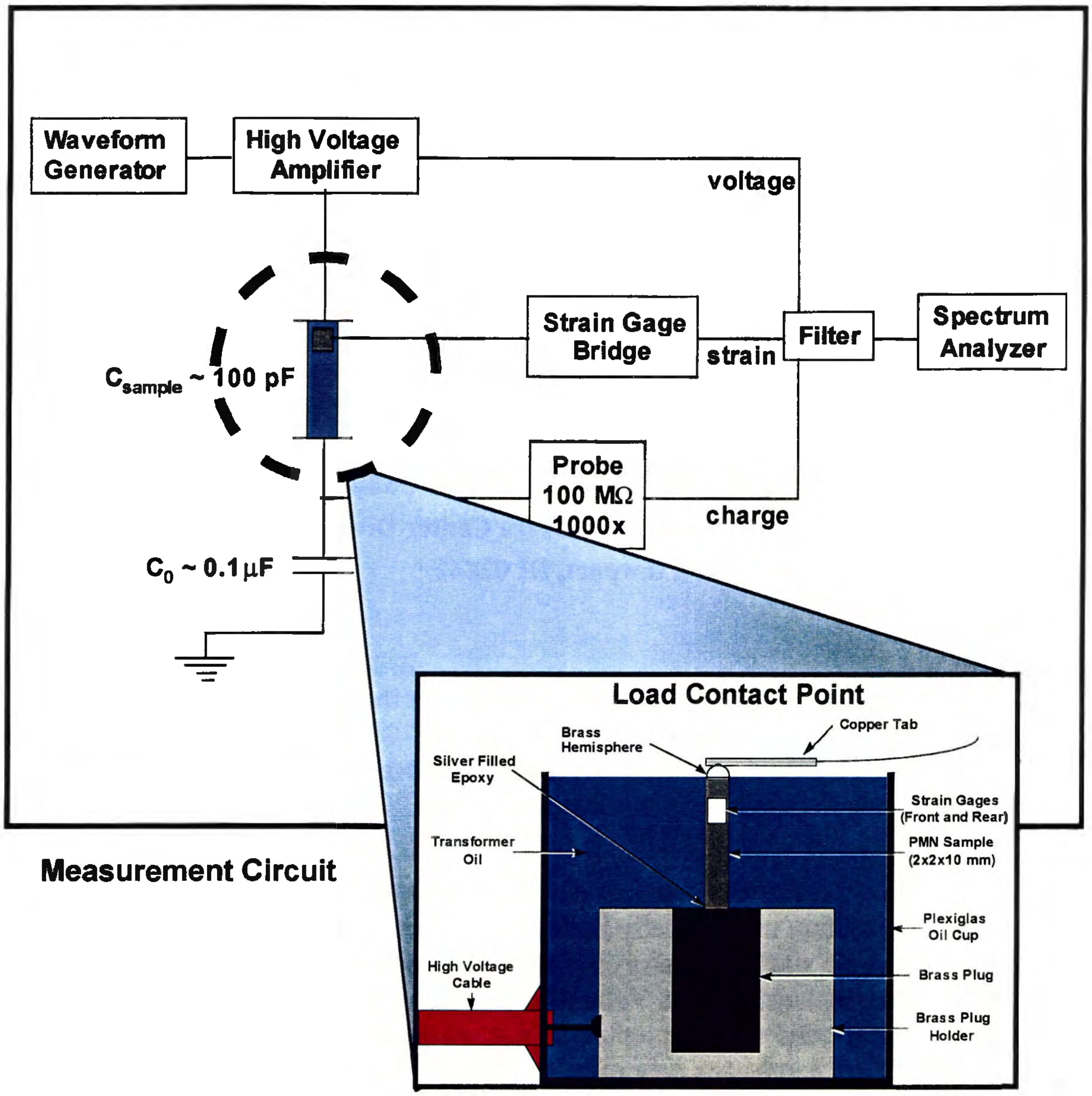
LARGE-SIGNAL CHARACTERIZATION OF PMN-PT-Ba (90/10/3)

Robert S. Janus, Mark B. Moffett, and James M. Powers
Naval Undersea Warfare Center Division
Newport, RI 02841

Large-signal measurements are reported for the relaxor ferroelectric, lead magnesium niobate - lead titanate (PMN-PT-Ba, 90/10/3), manufactured by Lockheed-Martin. The material has been formulated to produce optimal performance at 5° Centigrade for application in sonar transducers.

Charge and strain measurements were taken at 5° and 23° C on a material sample (2x2x10 mm) mechanically loaded with 2, 4, 6, 8, and 10 ksi of compressive stress. The sample was electrically dc biased and driven with 5 cycle, 10 Hz pulses to a peak electric field of 2 MV/m. Values for the piezoelectric coefficient, d_{33}, electrical permittivity, ε_{33}^T, and elastic compliance, s_{33}^E, were computed from the measurement data. These three parameters determine the coupling factor, k_{33}, which indicates the effectiveness of the material to convert electrical energy to mechanical energy. For the mechanical loads considered, k_{33} varied from 0.49 to 0.51 at 5° C, and from 0.44 to 0.49 at 23° C.

This work was supported by the Office of Naval Research (Code 332) and by Program Executive Officer, Undersea Warfare, Advanced Systems and Technology Office (PEO-USW-ASTO).

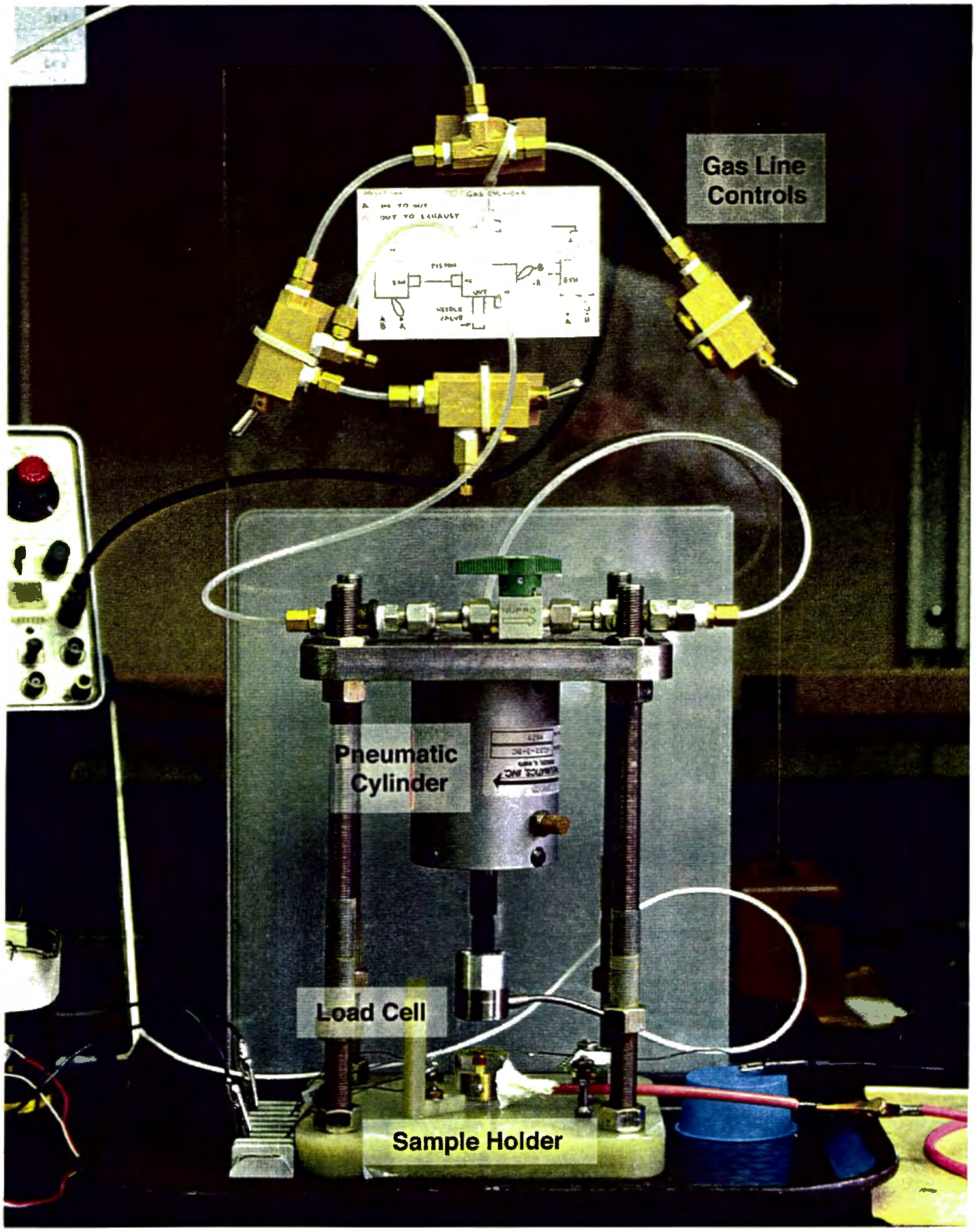


Measurement Circuit

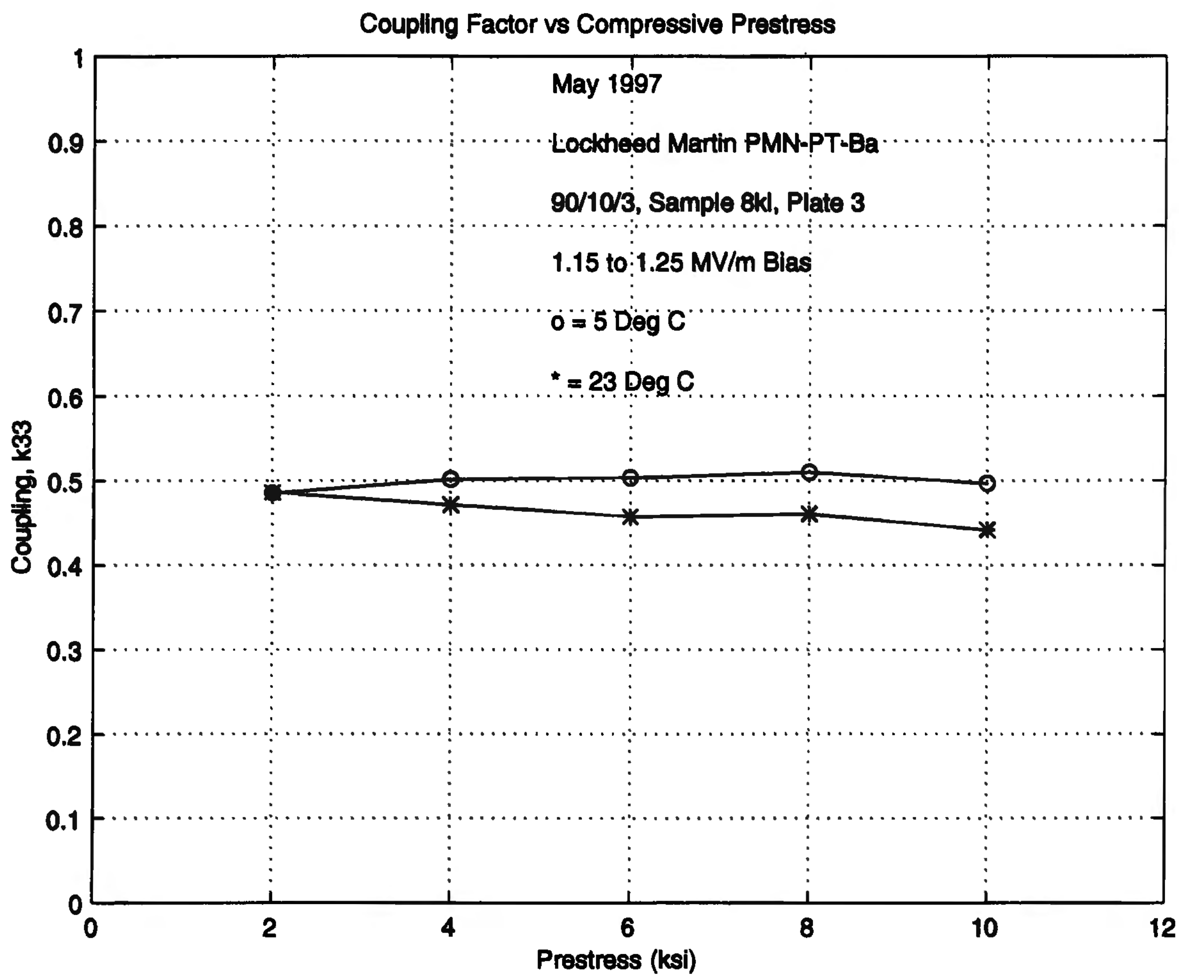
Sample Holder

Because the capacitance (i.e., electrical permittivity) of the test sample changes with electric field level, the electrical charge on the sample is determined by measuring the voltage, V_0, across a fixed capacitor , C_0, that is in series with the sample. This configuration is the basic Sawyer-Tower circuit that is commonly employed for such measurements. The charges, Q_{SAMPLE} and Q_0, on the capacitors are equal, i.e., $Q_{SAMPLE} = Q_0 = C_0 V_0$. For $C_0 >> C_{SAMPLE}$ nearly all the voltage, V_{TOTAL}, appears across C_{SAMPLE}.

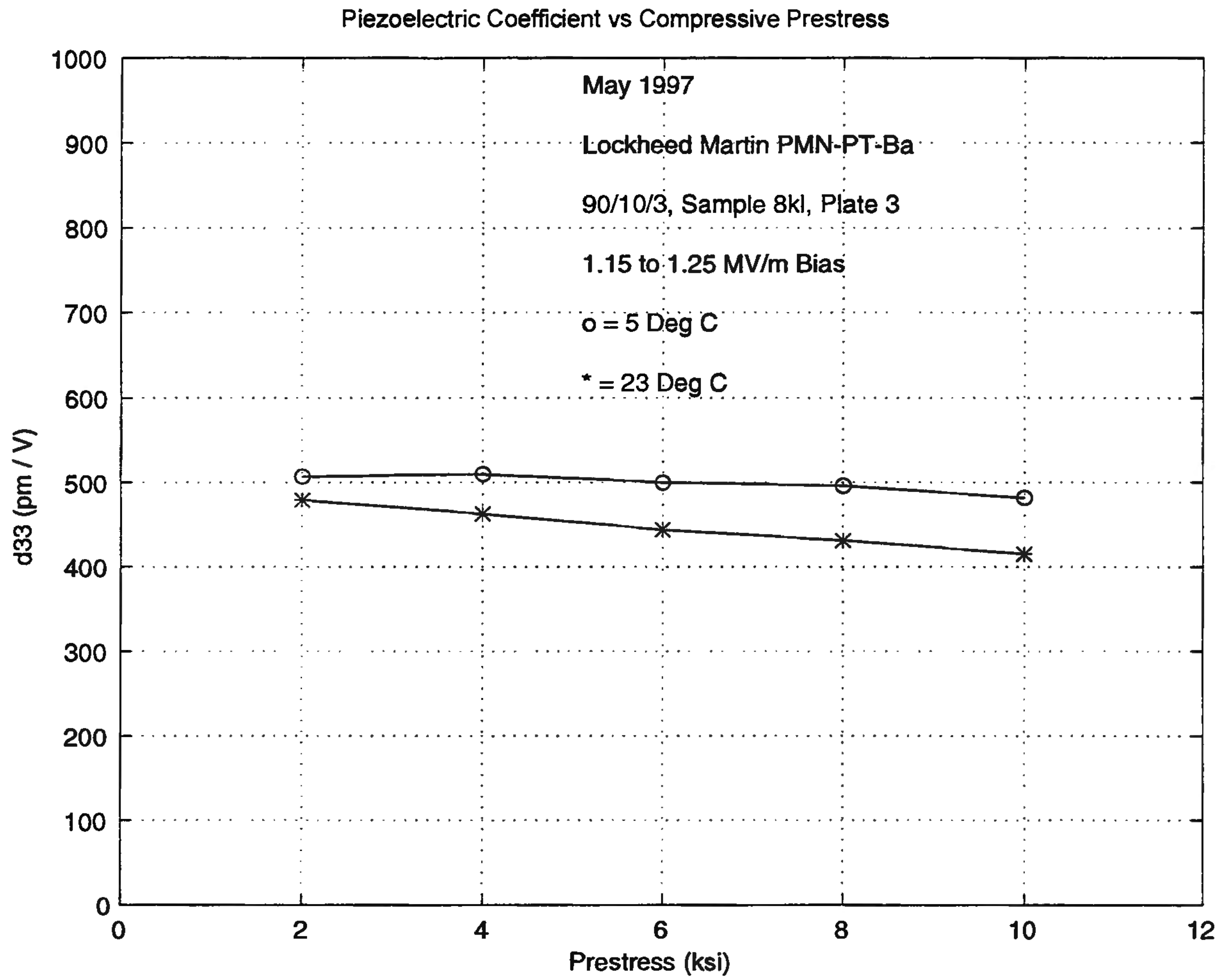
Strain data are obtained from two foil strain gages mounted on opposite sides of the sample. The two gages are wired together in series to cancel out bending strain components. Before connecting the gages in series, the individual outputs of both gages are simultaneously compared to assure that the applied mechanical load is uniformly distributed to minimize bending. Adjustment of the load is accomplished by moving the brass hemisphere that sits on top on the sample.



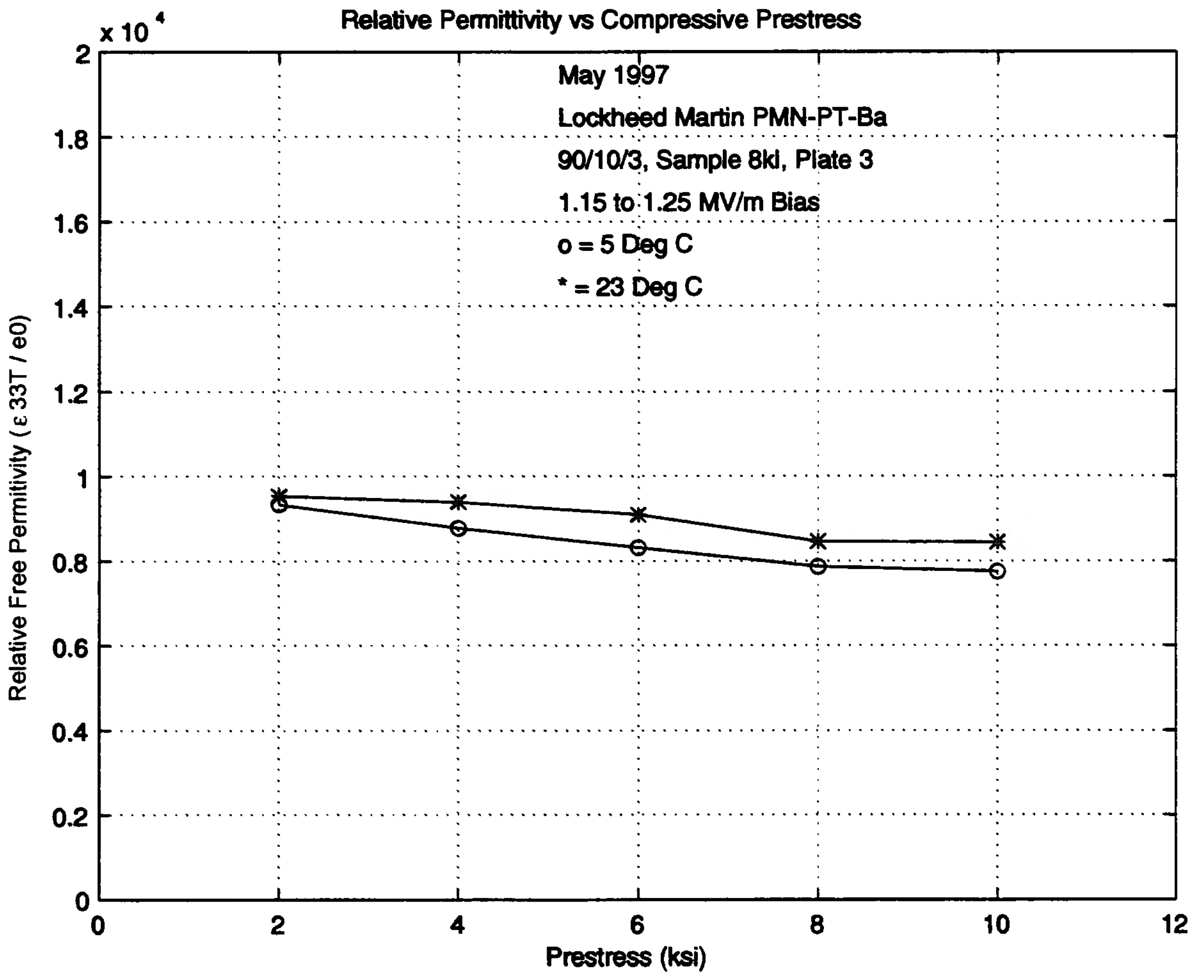
The mechanical bias is applied with a pneumatic cylinder which has a stiffness much less than that of the test sample. To reduce sliding friction, this cylinder has a "Rolling Diaphragm" rather than a conventional piston seal. The piston rod travels on a linear ball bushing to further minimize friction. Mechanical bias is monitored with the load cell.



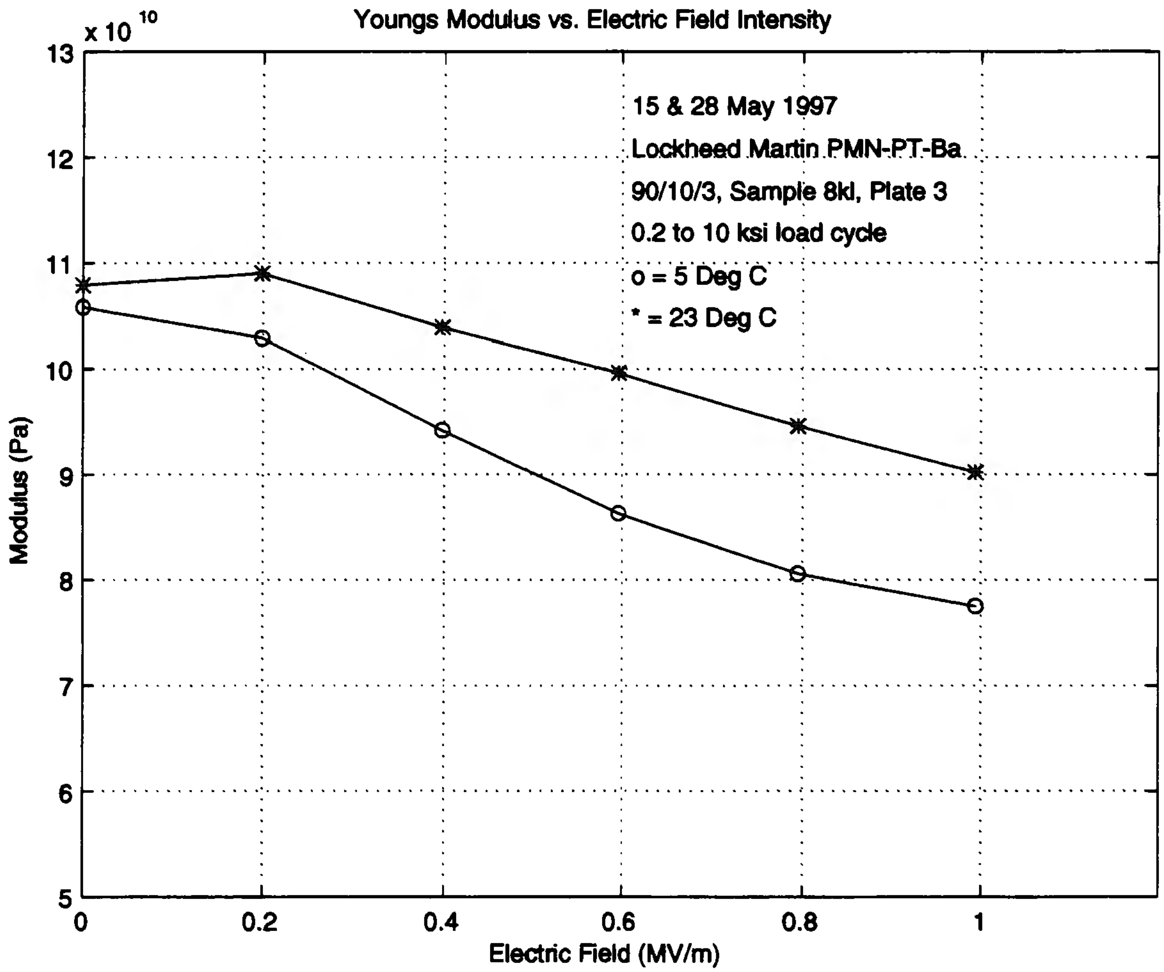
This plot summarizes the variation in coupling coefficient, k_{33}, with compressive stress. The results demonstrate that this material achieves a large-signal coupling factor, k_{33}, between 0.49 and 0.51 at the temperature at which it was designed to operate, 5° C. When compared with the data at 23° C, k_{33} is shown to be slightly enhanced at this lower temperature.



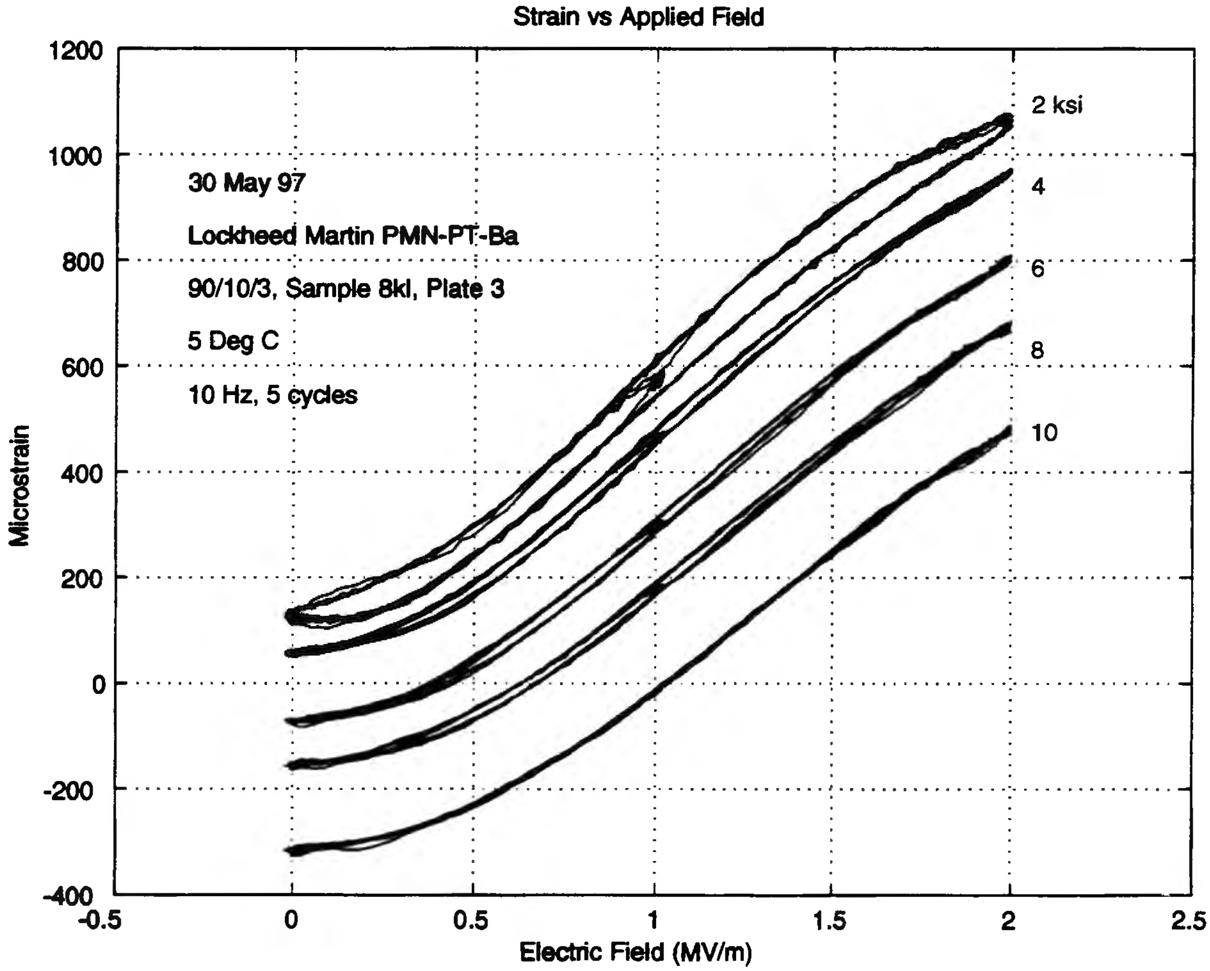
k_{33} is derived from the piezoelectric coefficient, d_{33}, elastic compliance, s_{33}^E, and electrical permittivity, ε_{33}^T: $k^2_{33} = d^2_{33} / (s_{33}^E \varepsilon_{33}^T)$. Values for these three parameters that were used to compute the corresponding k_{33} are shown in this and the two following plots.



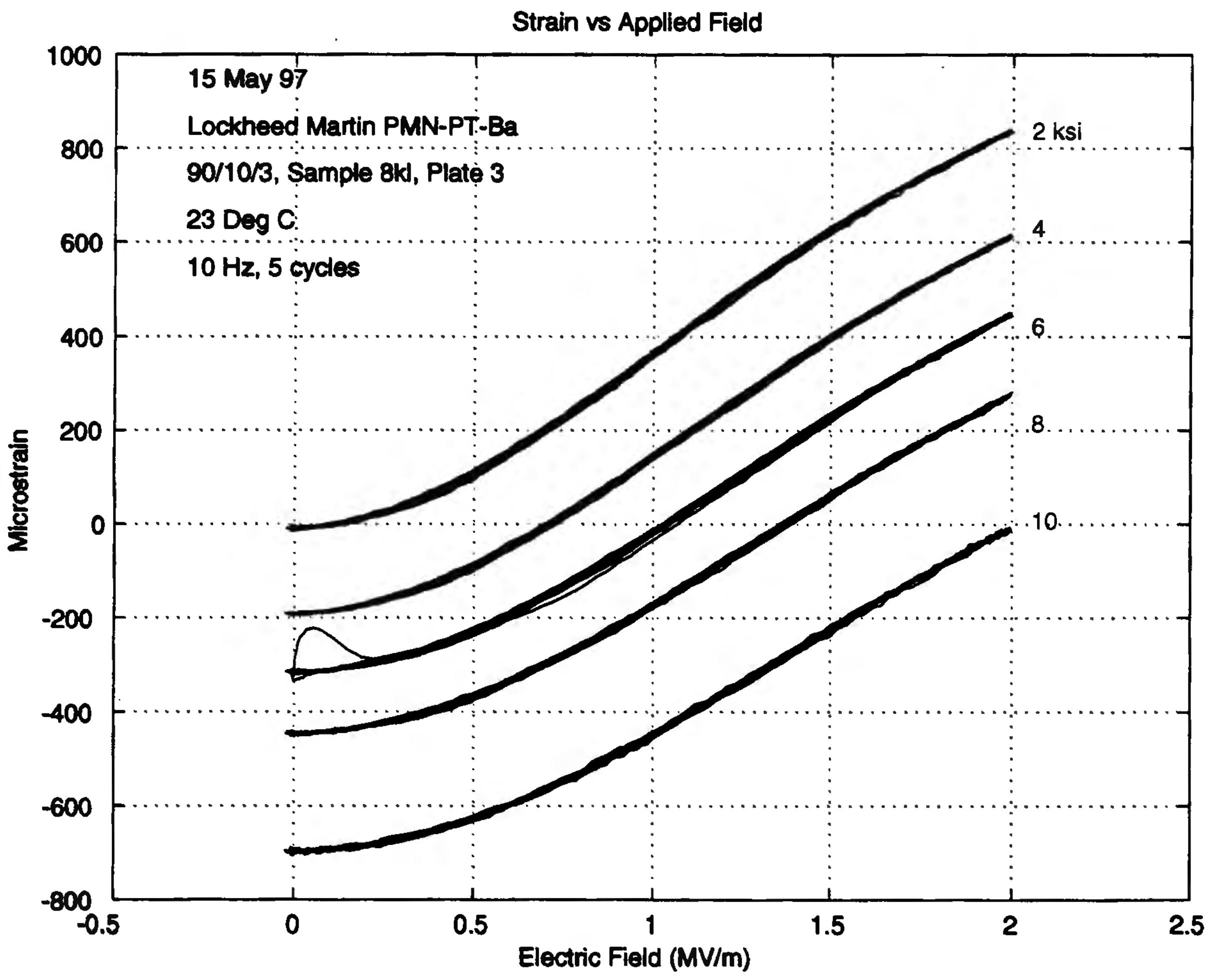
Here ε_{33}^{T} has been normalized by the permittivity of free space, ε_0.



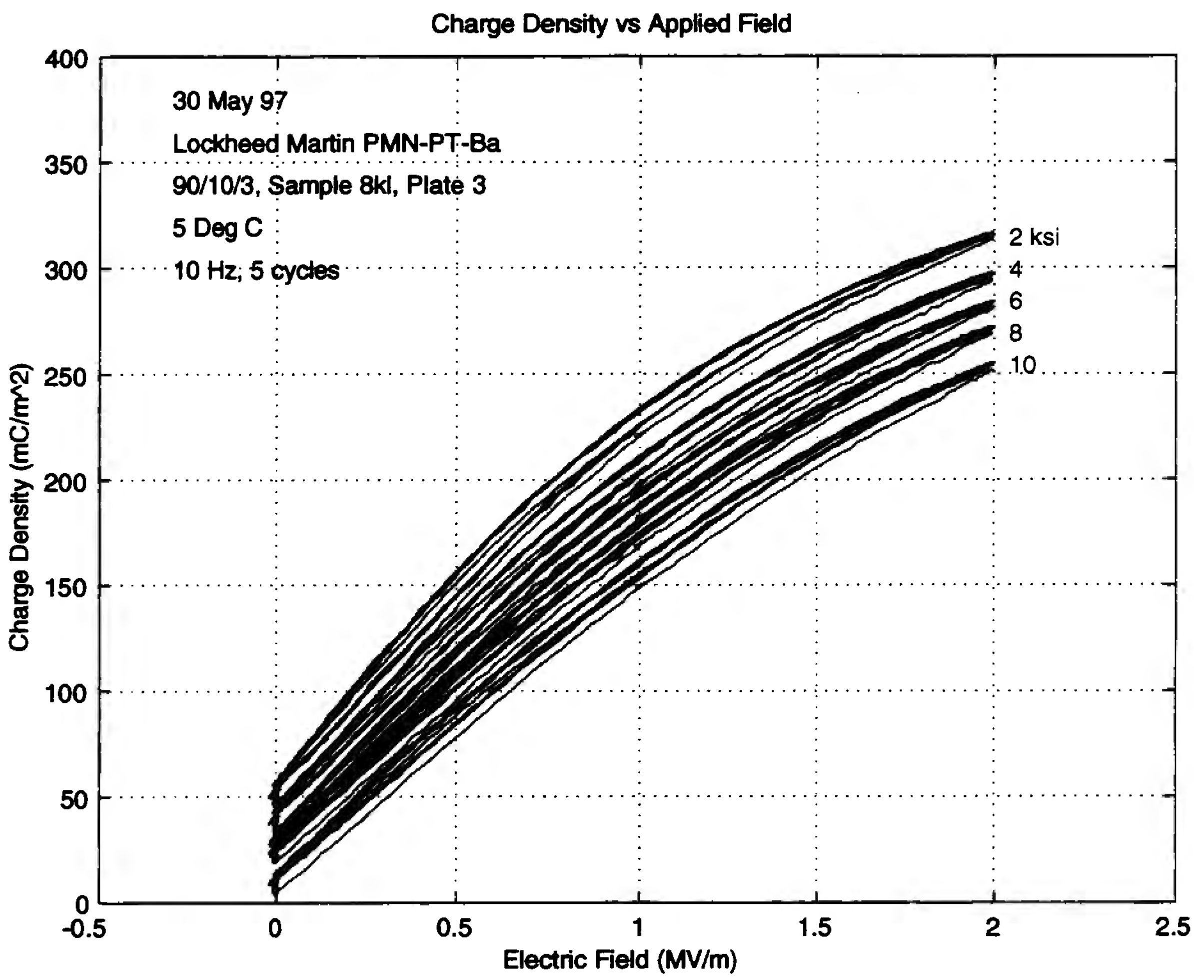
The line pressure to the pneumatic cylinder was ramped up and down to sweep the mechanical bias between 0.2 and 10 ksi while maintaining a constant electric field across the sample. Stress and strain data were simultaneously recorded and plotted against each other to obtain Young's modulus (i.e., $1 / s_{33^E}$). The resultant values of Young's modulus versus electric field are shown in this plot.



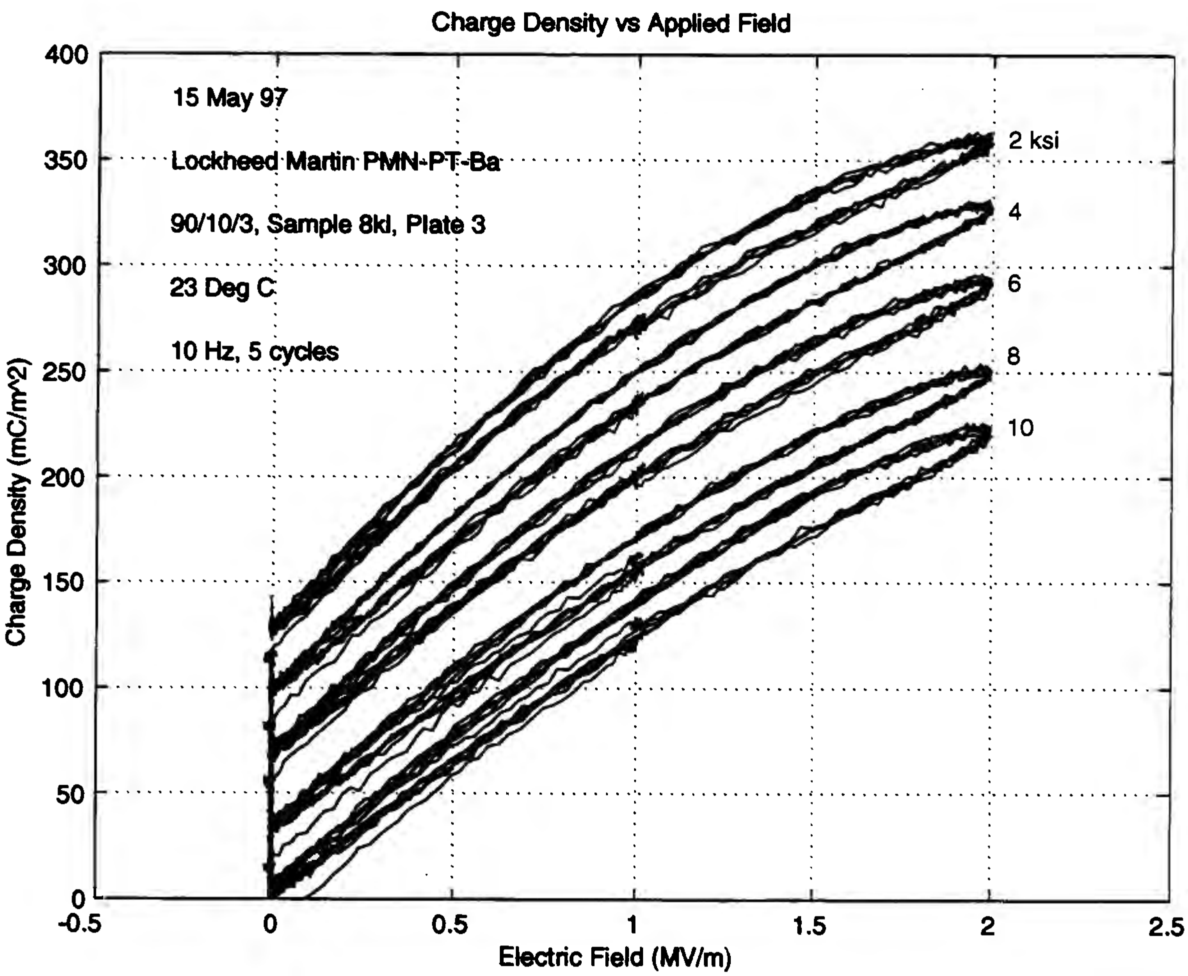
The PMN sample was driven with 5 cycle, 10 Hz sinusoidal pulses on a 1 MV/m dc pedestal to reach a peak field of 2 MV/m. The values of d_{33} were computed from the slopes of the hysteresis loops of strain, S_3, versus electric field, E_3, $d_{33} = \Delta S_3 / \Delta E_3$. This is a composite plot of the loops taken at 5° C for prestresses of 2, 4, 6, 8, and 10 ksi. The slopes were determined between the endpoints at 0.5 and 2 MV/m. These large signal data represent the drive levels that are required for actual sonar operation.



This second set of strain versus field loops was taken to determine d_{33} at 23° C. Each loop is averaged from 10 data records.



ε_{33}^T is equal to the slope of the charge density, D_3, versus E_3 loops, $\varepsilon_{33}^T = \Delta D_3 / \Delta E_3$. This is a composite plot of the 2, 4, 6, 8, and 10 ksi data at 5° C. The slopes were determined between the end points at 0.5 and 2 MV/m. The loops have been offset for clarity.



These charge loops at 23° C are more open than their 5° C counterparts. This may indicate that the material has more dielectric loss at 23° C than at 5° C, its design temperature.

CONCLUSIONS

- **Successfully measured coupling factor under high field ($\leq$ 2 MV/m) and high prestress ($\leq$ 10 ksi)**

- **Large-signal coupling factors (0.49 to 0.51) at 5° C for PMN-PT-Ba, 90/10/3 equal or exceed corresponding values measured at room temperature (23°C)**

- **Coupling factor varied with compressive stress by 4% and 10% at 5° and 23°C, respectively.**